

*Improved Computational Methods For Use In A  
Short-code Spread-spectrum Communications System*

1. In a method of processing spread spectrum waveforms transmitted by a plurality of users of a spread spectrum system, the improvement comprising:

computing a matrix representing cross correlations among the waveforms, said computing step including performing matrix calculation on at least a first one of two matrix components related by a symmetry property, and

estimating symbols transmitted by the respective users and encoded in said waveforms as a function of said cross correlation matrix.

2. The method of claim 1, wherein the step of computing the cross correlation matrix comprises computing a second one of the two matrix components as a function of the first matrix component by applying the symmetry property.
3. The method of claim 2, further comprising the step of generating detection statistics corresponding to the transmitted symbols as a function of the cross-correlation matrix.
4. The method of claim 2, wherein the step of applying the symmetry property comprises computing utilizing a symmetry property of the cross-correlation matrix defined in accord with the relation:

$$R_{lk}(m) = \xi R_{kl}(-m).$$

wherein

$R_{lk}(m)$  and  $R_{kl}(m)$  refer to (l,k) and (k,l) elements of the cross correlation matrix, respectively.

5. The method of claim 4, wherein the step of computing the cross-correlation matrix comprises computing a C matrix that represents correlations among time lags and short codes sequences associated with the waveforms transmitted by the users and a  $\Gamma$ -matrix that represents correlations among multipath signal amplitudes associated with the waveforms transmitted by the users.

6. The method of claim 5, wherein the step of calculating the C matrix comprises the step of computing a first one of two C-matrix components related by a symmetry property.
7. The method of claim 6, wherein the step of computing the C matrix comprises computing a second one of the two C-matrix components as a function of the first C-matrix component by applying a symmetry property.
8. The method of claim 7, wherein the step of computing the C matrix comprises computing the  $\Gamma$ -matrix in accord with the relation:

$$\Gamma_{ik}[m] \equiv \frac{1}{2N_l} \sum_{n=0}^{N-1} c_l^*[n] \cdot c_k[n-m]$$

wherein

$c_l^*[n]$  represents complex conjugate of the short code sequence associated with the  $l^{\text{th}}$  user,

$c_k[n-m]$  represents the short code sequence associated with  $k^{\text{th}}$  user,

$N$  represents the length of the code, and

$N_l$  represent the number of non-zero length of the code.

9. In a method of processing spread spectrum waveforms transmitted by a plurality of users of a spread spectrum system, the improvement comprising:

computing a matrix representing cross correlations among the waveforms, said computing step including

performing matrix calculation on at least a first one of two matrix components related by a symmetry property defined in accord with the relation:

$$R_{ik}(m) = \xi R_{k,l}(-m).$$

wherein

$R_{ik}(m)$  and  $R_{kl}(m)$  refer to  $(l,k)$  and  $(k,l)$  elements of the cross correlation matrix, respectively. and

computing a second one of the two matrix components as a function of the first matrix component by applying said symmetry property, and

generating estimates of symbols transmitted by the users and encoded in said waveforms as a function of the cross correlation matrix.

10. The method of claim 9, wherein the step of computing the cross-correlation matrix comprises computing a matrix (herein referred to as  $\Gamma$ -matrix) that represents correlations among short code sequences associated with the respective users in accord with the relation:

$$\Gamma_{lk}[m] \equiv \frac{1}{2N_l} \sum_{n=0}^{N-1} c_l^*[n] \cdot c_k[n-m]$$

wherein

$c_l^*[n]$  represents complex conjugate of the short code sequence associated with the  $l^{\text{th}}$  user,

$c_k[n-m]$  represents the short code sequence associated with  $k^{\text{th}}$  user,

$N$  represents the length of the code, and

$N_l$  represent the number of non-zero length of the code.

11. The method of claim 10, wherein the step of computing the cross-correlation matrix comprises computing a matrix (herein referred to as  $C$  matrix) representing cross-correlations among time lags associated with the transmitted waveforms and correlations among the short code sequences of the respective users as a function of the  $\Gamma$ -matrix in accord with the relation:

$$C_{lkq}[m] = \sum_m g[mN_c + \tau] \cdot \Gamma_{lk}[m]$$

wherein

$g$  is a pulse shape vector,

$N_c$  is the number of samples per chip,

$\tau$  is a time lag, and

$\Gamma$  represents the aforesaid  $\Gamma$  matrix.

12. The method of claim 11, wherein the step of computing the cross-correlation matrix (herein referred to as r-matrix) comprising calculating the r matrix as a function of the C matrix in accord with the relation:

$$r_{lk}[m] = \sum_{q=1}^L \sum_{q'=1}^L \text{Re} \left\{ \hat{a}_{lq}^* a_{kq'} \cdot C_{lkqq'}[m] \right\} = \text{Re} \left\{ a_l^H \cdot C_{lk}[m] \cdot a_k \right\}$$

wherein

$\hat{a}_{lq}^*$  is an estimate of  $a_{lq}^*$  which is the complex conjugate of one multipath amplitude component of the  $l^{\text{th}}$  user,

$a_{kq}$  is one multipath amplitude component associated with the  $k^{\text{th}}$  user, and

C denotes the aforesaid C matrix.

13. The method of claim 12, further comprising the step of computing detection statistics corresponding to the transmitted symbols as a function of the r matrix.
14. The method of claim 13, wherein the step of computing detection statistics comprises performing calculation in accord with the relation:

$$y_l[m] = r_{ll}[0]b_l[m] + \sum_{k=1}^{K_v} r_{lk}[-1]b_k[m+1] + \sum_{k=1}^{K_v} [r_{lk}[0] - r_{ll}[0]\delta_{lk}]b_k[m] + \sum_{k=1}^{K_v} r_{lk}[1]b_k[m-1] + \eta_l[m]$$

wherein

$y_l[m]$  represents detection statistic for the  $m^{\text{th}}$  symbol transmitted by  $l^{\text{th}}$  user,

$r_{ll}[0]b_l[m]$  represents a signal of interest, and

the remaining terms represent Multiple Access Interference (MAI) and noise.

15. The method of claim 14, further comprising the step of generating estimates corresponding to the transmitted symbols by applying a multi-stage decision-feedback interference cancellation (MDFIC) algorithm to the detection statistics.
16. The system of claim 15, wherein the step of applying the MDFIC algorithm comprises utilizing the relation:

$$\hat{b}_l[m] = \text{sign} \left\{ y_l[m] - \sum_{k=1}^{K_v} r_{lk}[-1] \hat{b}_k[m+1] - \sum_{k=1}^{K_v} [r_{lk}[0] - r_{ll}[0] \delta_{lk}] \hat{b}_k[m] - \sum_{k=1}^{K_v} r_{lk}[1] \hat{b}_k[m-1] \right\}$$

wherein

$\hat{b}_l[m]$  represents an estimate of the  $m^{\text{th}}$  symbol transmitted by the  $l^{\text{th}}$  user.

17. In a method of processing spread spectrum waveforms transmitted by a plurality of users of a spread spectrum system, the improvement comprising:

computing a matrix representing cross-correlations among the waveforms transmitted by the user as a function of a C matrix that represents correlations among the time lags associated with the transmitted waveforms and code sequences associated with the respective users, the computing step comprising computing a first one of two symmetry related matrix components of the C matrix,

generating estimates of symbols transmitted by the users and encoded in said waveforms as a function of the cross correlation matrix.

18. The method of claim 17, further comprising the step of computing a second matrix component of the C matrix as a function of the first matrix component by applying the symmetry property.
19. The method of claim 18, further comprising the step of generating detection statistics corresponding to the transmitted symbols as a function of the cross correlation matrix.
20. The method of claim 19, wherein the step of generating estimates comprises utilizing the detection statistics to generate said estimates.